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Influence of discharge current on 3 cells dynamic lead-acid batteries performance

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Abstract Lead-Acid Battery (LAB) is a secondary type battery that can work on static and dynamic electrolyte treatments. Dynamic batteries are a popular type of wet batteries recently due to high capacity storage, long life cycles, and simple designs. Dynamic Lead-Acid batteries have been chosen for this study to explore the characteristics of a lead-acid battery system consisting of 3 cells, 30% H_2SO_4 and a peristaltic pump. Twenty cycles of charge-discharge tests were carried out with a constant charging current of 1A until fully charged and the discharge current with variations of 0.2A; 0.3A; 0.4A and 0.5A. Experiments show that a smaller discharge current results in a longer duration of electric discharge. The cycle duration, capacity, and efficiency have decreased proportionally to the increase in the number charge-discharge cycles. Batteries with 0.2 A discharge current have shortest battery life. Batteries with 0.5 A discharge current have the greatest capacity performance.

1. Introduction

Indonesia produced 434.44 mtoe of energy and was still supported by 203.33 mtoe of energy imports in 2016. The electricity consumed was 225.91 TWh in the same year that the largest in ASEAN. Most of the electricity produced is obtained from steam power plants which are quite extensive in various parts of Indonesia, with a total capacity of 29,880.23 MW [1]. The government is determined to use Renewable Energy which are characterized by 70 energy contracts with a total of 1,214.16 MW in 2016 [2]. The construction of new renewable energy power plants requires energy storage media such as battery. Secondary battery is one of solution because this type of batteries is rechargeable.

Lead Acid Dynamic Battery (LADB) are one of the best options as an energy storage medium for new renewable power plants. This is due to several advantages of dynamic batteries such as high of durability, energy performance, large density, capacity and low prices per component [3-6]. Dynamic batteries are batteries that have electrolyte liquids and can flow. So, it needs another container outside the battery to hold electrolytes. Dynamic battery reported has better performance than static batteries. Besides that, the characteristics of the dynamic battery are identical to conventional static batteries [7, 8].

In the previous research, a single cell dynamic battery with a pair of electrodes with an area of 31 × 7.5 cm^2 and an electrolyte concentration of 30% showed the best performance during the initial 8

cycles [9-11]. The dynamic single-cell lead-acid battery has the best performance when given 1A charged-discharged load. Giving loads below 1A results in unoptimally voltage, capacity, and energy efficiency performance [12]. Based on its lifetime, the factors that influence the life of the dynamic battery are the electrolyte flow rate, electrolyte concentration, electrolyte volume, electrode cross-sectional area and the provision of current loads provided by the battery during the filling and emptying process [13]. However, the explanation of 3 cell dynamic batteries is still very limited. The aims of the research is to obtain information about battery characteristic and its capacity performance.

2. Experiment Method

Four pieces of 3 cell lead-acid batteries are needed for create the dynamic batteries, with the total number of electrodes in each cell being 4 Pb and 3 PbO_2 arranged like sandwiches, each electrode separated by a membrane, and cells arranged in series.
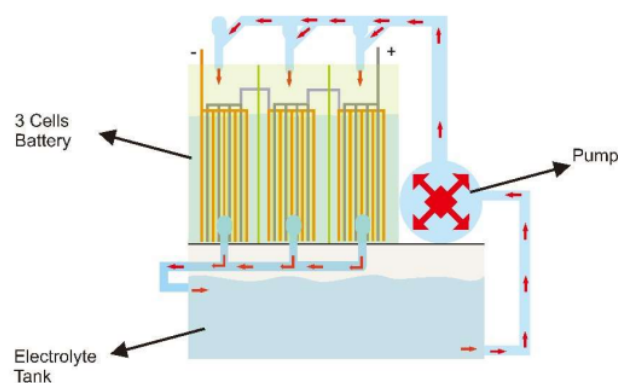

Figure 1. Three cell dynamic battery scheme.

Both electrodes are 4.5×7.5 cm^2 in size which is the size of each cell is 3×5×9 cm^3 and electrolytic tank of 500 ml. Turnigy Accucell 50w was used as Battery Management System (BMS) and 3W / 4.5V peristaltic pump as electrolyte pump. The dynamic battery scheme is shown in Figure 1. Battery testing is carried out by 1A charging and discharging with a current variation of 0.2A (called D2 battery); 0.3A (D3); 0.4A (D4) and 0.5A (D5) without being time limited to as many as 20 full cycles or until the battery fails to charge to obtain overall battery performance.

3. Result and Discussion

Based on experiment, it is known that all 3-cell lead acid dynamic batteries have a maximum charging voltage of 7.21 V during 20 full cycles. When the battery reaches this voltage, the charging current gradually decrease until no more current can be inserted into the battery automatically by BMS. In this condition, the battery can be said to be fully charged. The discharging process is carried out after the battery is fully charged until the battery reach voltage of 5.41 V. This voltage is the minimum voltage that can be achieved by lead-acid based batteries, which is also a safety voltage carried out by BMS. So, that the battery is not quickly damaged. The amount of time needed to do a full cycle depends on the electric currents and the amount of battery capacity. The smaller current in used, the longer full cycle test to be. This is due to the slowness of chemical processes that occur in cells. The charging and discharging process change the value of H_2SO_4 electrolyte density. Density of H_2SO_4 electrolytes increased up to $\pm$ 1,300 Kg/m^3 in value when the battery is fully charged. While battery fully discharged, the density decreased up to $\pm$ 1,175 Kg/m^3 indicate there is chemical reaction during this process. The change of density value prove that the reaction occurs in the battery runs in two directions or "reversible and produced water during discharging process. Based on chemical reactions, lead acid-based batteries

are no longer able to provide electrical energy when the electrolyte have been turned into water mostly (around 20%).

Batteries have charging and discharging time characteristics and shown in Table 1 to Table 2. The performs of the battery system decreases every next full cycle until finally the battery fails to be charge. The D2 battery has an average time per cycle of 19.45 hours. Battery D3 has an average time per cycle of 18.04 hours. Battery D4 has an average time per cycle of 20.17 hours after completing 20 full cycles. Battery D5 completes 20 full cycles with an average time of 18.08 hours. This data shows that by using more load currents will affected the duration of battery cycle. Decreasing cycle time for all batteries due to the appearance of $PbSO_4$ deposits which cannot be converted back into Pb, this inhibit the electron transfer process because the deposit is an insulator. These deposits are the reason for the decline in battery performance. The appearance of $PbSO_4$ is unavoidable and this is the natural character of lead-acid based batteries. The battery is damaged when the electrolyte density after the charging and discharging process is equal value. Battery capacity touches the lowest value when the electrolyte density does not change after the charging process. Charging and discharging times also dropped significantly. From the previous explanation, it was concluded that battery D2 had the shortest life cycle compared to other batteries, which is only 16 full cycles from 20 cycles planned. At the end of battery life, the battery also produces the lowest voltage. Based on the data, the range of

Table 1. Capacity and Open Circuit Voltage of Dynamic Lead-Acid Battery (DLAB) During Charge-discharge Test (charging = 1A).

Cycle	D2 Battery			D3 Battery			D4 Battery			D5 Battery		
	C_C	C_D	V_{OV}	C_C	C_D	V_{OV}	C_C	C_D	V_{OV}	C_C	C_D	V_{OV}
1	7,648	5,540	6.45	5,570	5,570	6.47	7,788	6,049	6.75	7,580	6,860	6.80
5	5,566	3,966	6.75	3,936	3,936	6.56	7,511	5,099	6.23	6,140	5,085	6.27
10	2,788	1,231	6.49	2,257	2,257	6.47	6,375	3,843	6.38	5,807	4,352	6.14
15	1,158	297	6.17	2,566	2,566	6.37	4,004	2,808	6.34	4,945	3,748	6.41
20	-	-	-	2,416	2,416	6.23	4,639	2,936	6.64	3,870	2,946	6.38

*C_C = Capacity after charging (mAh), C_D = Capacity after discharging (mAh) and V_{OV} = Open circuit Voltage (V)

Table 2. Duration of Charge-Discharged test and density of Electrolyte During Experiment. (charging = 1A).

Cycle	D2 Battery				D3 Battery				D4 Battery				D5 Battery			
	t_C	ρ_C	t_D	ρ_D	t_C	ρ_C	t_D	ρ_D	t_C	ρ_C	t_D	ρ_D	t_C	ρ_C	t_D	ρ_D
1	11.6	1.30	26.3	1.17	11.3	1.32	15.9	1.26	10.8	1.30	15.1	1.17	9.9	1.30	13.6	1.18
5	8.3	1.31	21.4	1.27	10.2	1.33	12.9	1.28	11.0	1.30	13.4	1.17	8.6	1.32	10.1	1.18
10	5.7	1.33	5.8	1.27	10.1	1.33	7.4	1.29	9.9	1.30	9.6	1.26	9.7	1.30	8.7	1.28
15	3.5	1.30	1.4	1.30	6.1	1.33	8.4	1.28	7.3	1.31	7.0	1.28	7.7	1.32	7.4	1.27
20	-	-	-	-	7.3	1.33	7.9	1.28	10.3	1.31	7.3	1.27	6.2	1.32	5.9	1.28

*t_C = Charging time (h), ρ_C = electrolyte density after charging (g/cm³), t_D = Discharging time (h) and ρ_D = electrolyte density after discharging (g/cm³)
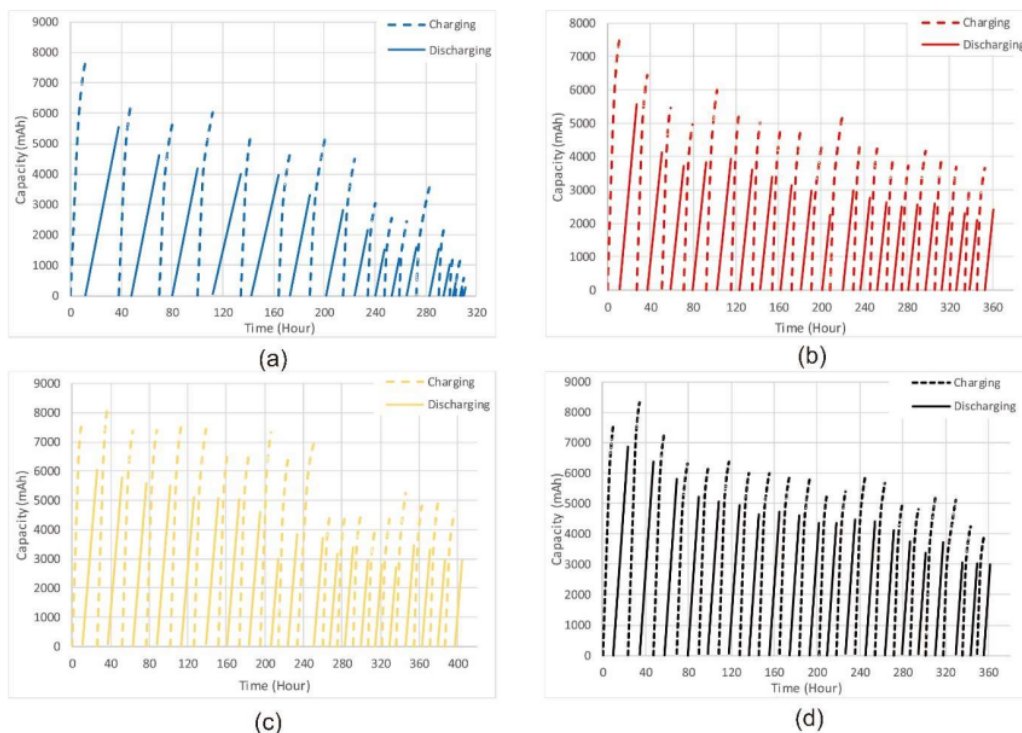
Figure 2. Overall charging and discharging capacity curve of (a) D2 battery, (b) D3 battery, (c) D4 battery, (d) D5 battery. The discharging capacity curve has never been higher than the charging capacity due to battery efficiency. Both charging and discharging curves fluctuate but have a tendency to decrease with increasing usage cycle.

Beside causing a decrease in the cycle life due to the deposit of $PbSO_4$ which covers most of the Pb electrode, this has an impact on the decrease of battery capacity. Both the charging and discharging capacity are shown in Figure 2, explain that the battery can store charges during charging process and then flow out the charges during discharging process. The value of the charging and discharging capacity of all tested batteries fluctuates and tends to decrease. The battery can be said to be damaged when the remaining capacity is only 20% of its initial capacity, in this condition the battery electrolytes and or electrodes needs to be replaced in order to have optimal performance. Each battery never has a discharge capacity higher than its charging capacity, this is due to the efficiency factor of the battery. The D2 battery that has the shortest life cycle has an average capacity reduction around 351 mAh/cycle with a first cycle capacity of 5,540 mAh, at the end of its life cycle D2 battery capacity is 271 mAh. The D2 battery can be said to be damaged in the 13th cycle because the remaining capacity is 1,025 mAh or equivalent to 18.5% of its initial. The battery reduction rate of D3 is 166 mAh/cycle, with the first cycle capacity of 5,570 mAh and after 20 full cycles were completed, the remaining capacity was 2,416 mAh or equivalent to 43.38% of initial capacity. Battery D4 has an average capacity reduction rate of 164 mAh/cycle. The first cycle capacity is 6,045 mAh and become 2,936 mAh after running 20 full cycles or equivalent to 48.54%. Battery D5 with an average capacity reduction rate of 206 mAh/cycle for 20 full cycles remain 2,946 mAh or 42.94% of his capacity from 6,860 mAh in the beginning. Battery D5 has shown the best capacity performance than the other batteries.

4. Conclusion

The dynamic battery of 3 cell lead acid has a working voltage ranging from 6.14 - 6.8 V after testing up to 20 cycles. The smaller discharge current results in longer battery discharge time, the battery capacity gets smaller and produces a greater open voltage average. Capacity efficiency decreases significantly when the electrolyte density has the same value during charging and discharging process.

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